Electric Generators Fitted to Wind Turbine Systems: An Up-to-Date Comparative Study

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This paper describes a comparative study allowing the selection of the most appropriate innovative structures for electrical machines for a wind turbine system. This study is based on an exhaustive review of the state of the art and on an effective comparison of the performances of the three main conventional electric generator in wind energy application system that are the Doubly-Fed Induction Generator (DFIG), the Squirrel-Cage Induction Generator (SCIG), the Permanent Magnet Synchronous Generator (PMSG), and an innovative machine that is the Switched Reluctance Generator (SRG). The main conclusion drawn by the proposed comparative study is that the innovative switched reluctance generator is able fulfills the major requirements of a wind energy system.

Keywords: Wind turbine; electric generators; comparison.

1. Introduction

In recent years, the wind energy know a rapid growth because, it plays a more important role in global electricity generating, the use of wind is discussed in [1], it is becoming more and more popular with the passage of time; the global wind energy capacity has grown rapidly and has become the fastest growing renewable energy technology [2-3]. Various wind turbine concepts have been developed and different wind generators have been used in researching and marketing, so as to efficiently utilize the wind power [2-4], [5].

The choice of the type of aero-generators is however difficult. In fact, the choice of electric generator for wind power mainly depends on several criteria: structure, converter topology, environment (location where the turbine is installed), performances, and cost. Therefore, selecting the most appropriate electric generator for a wind power is a challenging task.

In an industrial point, the major types of electric generators adopted or under serious consideration for wind power include the early aero-generator concept is using a standard Squirrel-Cage Induction Generator (SCIG) and a multi-stage gearbox, directly connected to the grid, the Doubly-Fed Induction Generator (DFIG), the Permanent Magnet Synchronous Generator (PMSG), and an innovative machine that is the Switched Reluctance Generator (SRG). Cross-sections of each of these four generator types are provided in Fig. 1.

Moreover, according to an exhaustive review of the state of the art related to wind power, it is observed that investigations on doubly-fed induction generators are highly dominant, whereas those on permanent magnet synchronous generator are used increasing continuously in small wind power, those on cage induction are dropping while those on switching reluctance generators are gaining much interest [2-3], [6-7].

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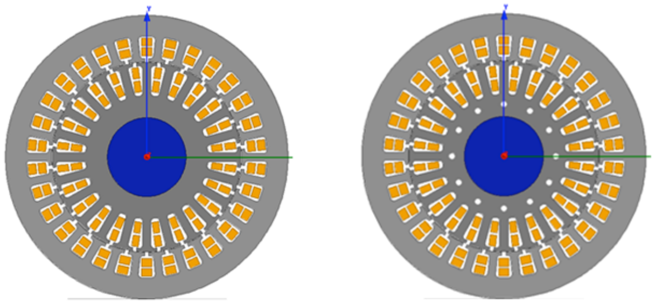
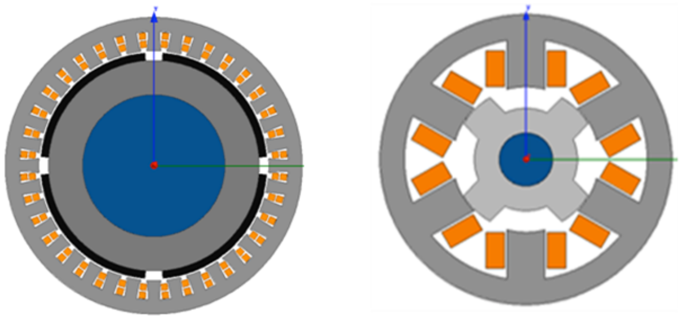
In this paper, potential candidates in wind power are presented and evaluated according to the major requirements of a wind generating system. Conclusions are then drawn to identify the most potential candidate of wind energy.



(a) DFIG. (b) SCIG.



(c) PMSG. (d) SRG.

Fig. 1. Wind power generators.

2. Wind power requirement

2.1. Wind power configuration

Modern wind turbines divided into two basic groups; the horizontal-axis variety (HAWT), (Fig. 2), like the traditional farm windmills used for pumping water, and the vertical-axis design (VAWT), (Fig. 2), like the eggbeater Darrieus model or Savonius model, most large modern wind turbines are horizontal-axis turbines.

The proposed comparative study has been done on the horizontal-axis wind turbine (HAWT) configuration (Fig. 3). In fact, the difference between them is at the level of the shaft, where the mounting of the shaft determines the direction and shape of the propeller blades, which means that horizontal and vertical wind generators can often vary in appearance.

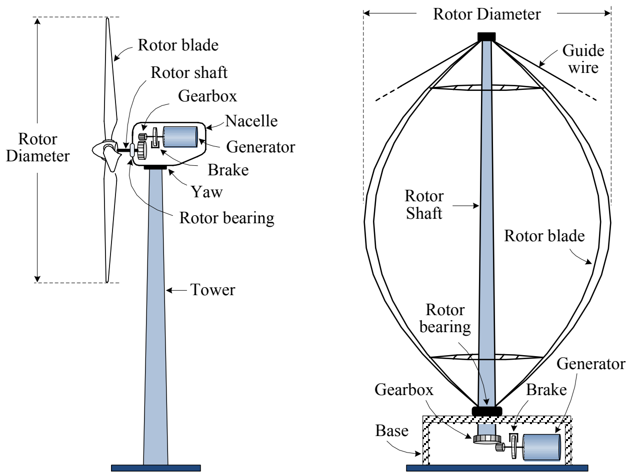


Fig. 2. HAWT and VAWT configurations [8-9].

Both designs have their advantages and disadvantages [1]. Historically, horizontal axis wind generators have been more popular and widely used which means its design and technologies are more widely understood and developed. Vertical axis wind generators are still a large unknown to many wind power users and technicians. Its technologies and designs are still in the process of being more widely understood.

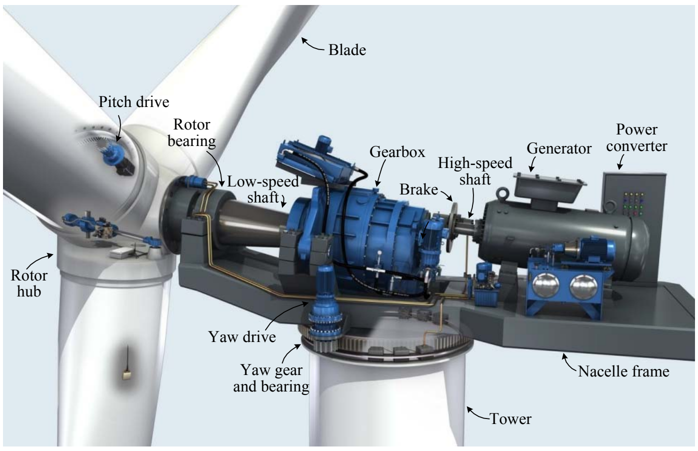


Fig. 3. HAWT subsystems [8-9].

2.2. Conversion methods of wind energy

The first requirement of the system is the existence of a wind flow sufficiently strong, a typical wind profile has been calculated in [5], [6] and is shown in Fig 4. Where the aerodynamic power is related with the wind speed v_w by equation (1).

$$P_t = \frac{1}{2}\rho S v_w^3 C_p(\lambda) \tag{1}$$

Where:

ρ is the air density [kg / m^3],

S is the surface active of the turbine blade [m^2],

v_w is the wind speed [m / s],

$C_p(\lambda)$ represents the aerodynamic conversion factor for the wind turbine,

C_p varies with λ the tip speed ratio, which connects the wind speed with the rotor speed as given by equations (2) its behavior in modern turbines is represented in Fig 5.

$$\lambda = W \frac{R}{v_w} \tag{2}$$

Where: R [m] is the blade radius, W is the rotational rotor speed [rad / s].
Finally, the torque developed on the rotor of the turbine is determined by (3):

$$T = kv_w^2 \tag{3}$$

In a direct-drive power the generator rotates at the same speed as the turbine, therefore the same torque.

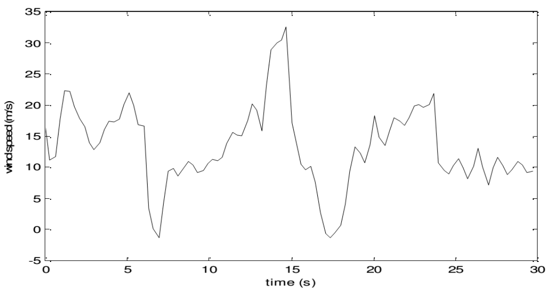


Fig. 4. Typical wind profile [6].

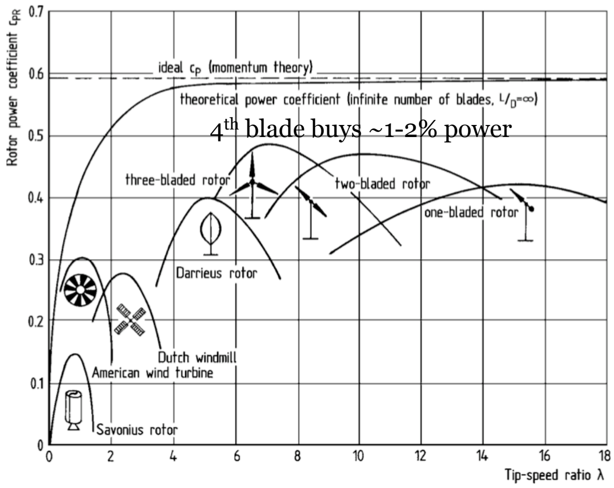


Fig. 5. Power coefficient Cp for different wind turbines [10].

2.3. Generator characteristics versus wind power

The major requirements of generators for wind turbine, as mentioned in past literature, are summarized as follows [1-6].

- High torque and high power density;
- Reduction of the system parts;
- High efficiency;
- Lowest maintenance;
- High reliability and robustness for various wind operating conditions;
- Reasonable cost.

Moreover, in the extreme environments, the electric generator should be fault-tolerant [11-12]. Finally, in an industrial point of view, an additional selection criterion is the market acceptance degree of each generator type, which is closely associated with the comparative availability and cost of its associated power converter technology, in [13] many different generator–converter combinations are compared on the basis of topology, cost, efficiency, power consumption and control complexity.

Figure 6 illustrates one of the major factors affecting the performance of a wind power is its power response to different wind speeds. This is usually given by the ideal power curve of the wind turbine, which reflects the aerodynamic, transmission and generation efficiencies of the system in an integrated form. In this example, the rated power of the turbine is 2 MW. The performance characteristic depending on the wind speed comprises three distinct zones:

- Zone I: where $P_t = 0$, the turbine does not produce power.
- Zone II: speed of a turbine is the minimum wind speed at which the system begins to produce power. The $v_w^{\min}$ speed varies from turbine to turbine, depending on its design features. However, in general, most of the commercial wind turbines $v_w^{\min}$ is at velocities between 3 to 5 $[m/s]$.
- Zone III: the turbine is restricted to produce constant power P_r.

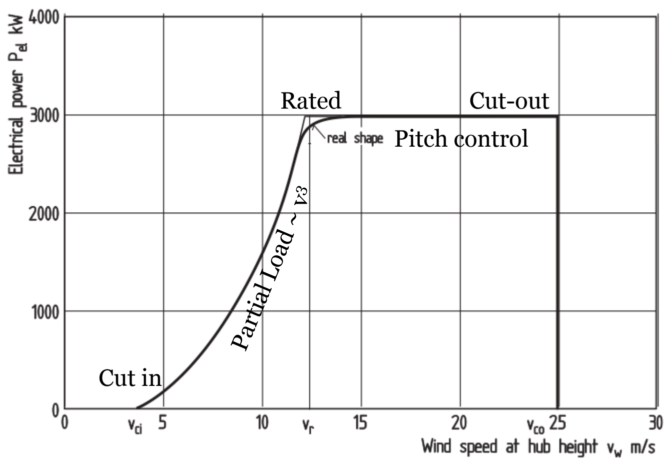


Fig. 6. Typical power curve of a wind turbine [10].

3. Comparative study

Generator is one of the most important components of a wind energy conversion system (second important component), generator of a wind turbine has to work under fluctuating power levels. Different types of generators are being used with wind turbines. These generators can either be induction (asynchronous) generators or synchronous generators and recently appeared innovative machine.

3.1. Squirrel-Cage Induction Generator (SCIG)

The first production of electrical energy with wind power was 1887 by Charles Brush in Cleveland, Ohio. The rated Power of the used dc-generator was 12kW and was designed to charge batteries. The induction machine was used at the first time in 1951 [15]. But, in wind power using squirrel-cage induction generators (see Fig. 7), must be operated at a constant speed, which is not favored at the varied wind speed application. However, SCIG drives have bulky construction, low efficiency, low reliability and need of maintenance, also the existing of slip ring, brush and three-stage gearbox increases the system mass and cost, also electrical and mechanical loss. Recently, squirrel-cage induction generators are dropping in this application.

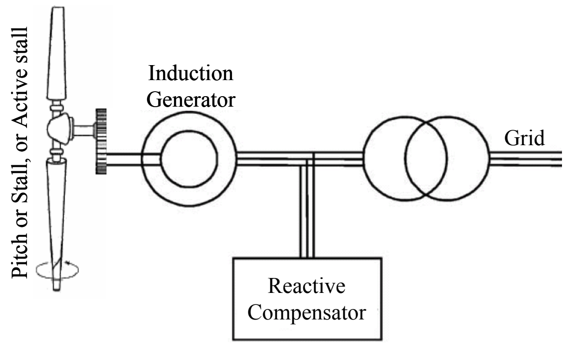


Fig. 7. Scheme of a SCIG wind generating system [5].

Typical torque speed curve of the machine is shown in Fig. 8. Hence, the rotor always rotates at a speed slightly lower than the synchronous speed. The difference between the synchronous speed N_s and the rotor speed N_r is termed as the slip of the motor. Thus, the slip (S) is given by:

$$S = \frac{N_s - N_r}{N_s} \tag{4}$$

The synchronous speed of the induction motor is given by:

$$N_s = \frac{120f}{p} \tag{5}$$

Where f is the frequency and p is the number of poles.

When we couple this machine with a grid integrated wind turbine, initially it draws current from the grid as in case of a motor. The speed picks up and the rotation of the wind turbine causes the system to exceed the synchronous limit N_s.
Thus, rotor moves faster than the rotating magnetic field. At speeds higher than N_s, the torque is negative as seen from Fig. 8. Thus, current flows in the opposite direction that is from the system to the grid. Thus the machine functions as a generator when it is driven by an external prime mover, like the wind turbine in our case [14-16].

Moreover, the development of rugged solid-state power semiconductors made it increasingly practical to introduce DF induction and synchronous generators drives that are mature to replace IG drive in wind power [2-15-17].
For illustration, Fig. 9 shows industrial wind power induction generators [18-19].

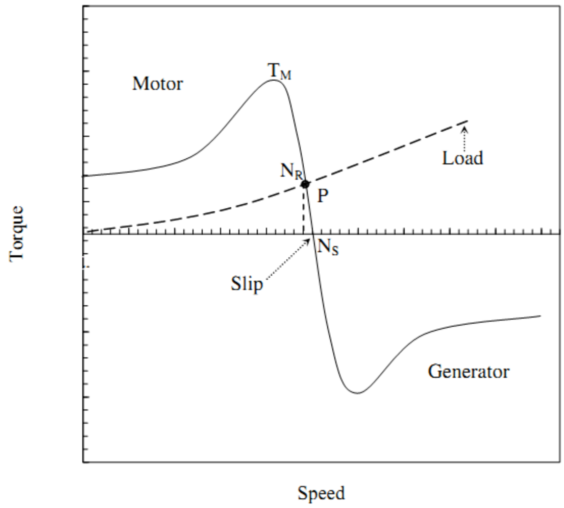


Fig. 8. Characteristics of a typical induction machine [14].

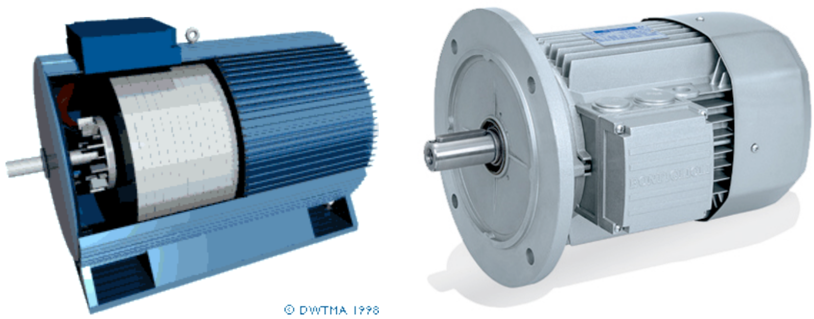


Fig. 9. Industrial induction generator for wind turbine.

Electric system:	
rated power	3.170 kW
rated voltage	10/20/30 kV
Rated frequency	50 Hz
Generator Type:	DFIG

3.2. Doubly-Fed Induction Generator (DFIG)

Today over 70% of the wind turbines are build up with Doubly-Fed Induction Generator (DFIG) [15]. Many manufacturers, such as Vestas, Gamesa, GE and Repower, have provided the wind turbine system with this concept [2] Fig. 10.

In fact, DFIG has great improvement comparing with the SCIG concept, in [4], [20] there are summary of DFIG.

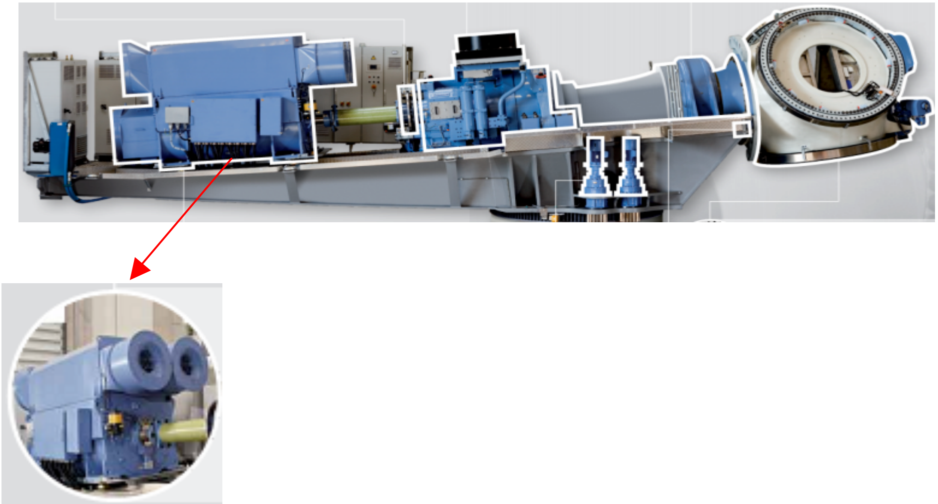


Fig. 10. Industrial DFIG for wind turbine of the REpower manufacturer [21].

This system (Fig. 11) consists of a wind turbine with DFIG. This means that the stator is directly connected to the grid while the rotor winding is connected via slip rings to a converter. As also seen in the Fig. 12 the DFIG can operate both in motor and generator operation with a rotor speed range of $\pm\Delta w_r^{max}$ around the synchronous speed, w_1. The dynamic behavior model and their control system of the DFIG is considered in [23-25].

Moreover, new types of generators which may change the configuration of the wind energy are being developed, where this new concept eliminates most of the mechanical parts, such as brush, slip ring and gearbox, that are considered drawbacks to this concept, as a result, reducing the mass and cost of the system and achieving high reliability and availability. Finally, it should be noticed that most research works tend to use the DFIGs in wind energy, as they have excellent performance [20-25]. Such as in [26] adjustable speed operation of the DFIG offers many advantages to reduce cost and has the potential to be built economically at power levels above 1.5 MW for off-shore applications.

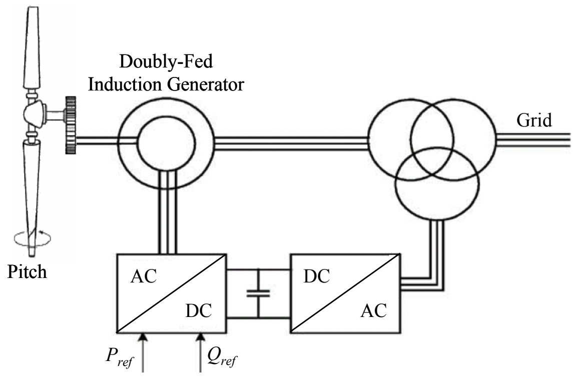


Fig. 11. Scheme of a DFIG wind generating system [5].

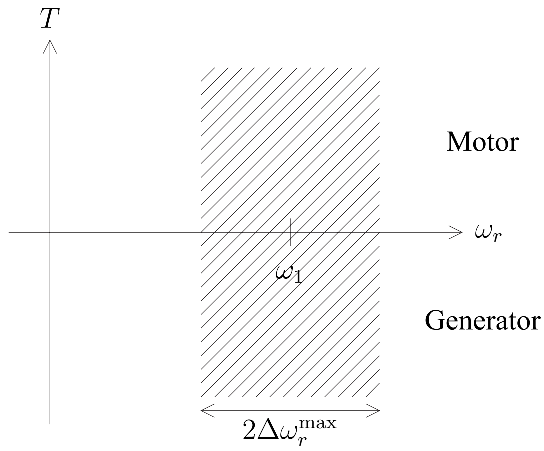


Fig. 12. Torque-speed characteristic of a DFIG [22].

3.3. Permanent Magnet Synchronous Generator (PMSG)

Permanent magnet synchronous generators (PMSG)s consists of a rotor and a three-phase stator similar to an induction generator, is shown in Fig. 1(c), are most capable of competing with induction generators for the wind power applications. In fact, they are adopted by well-known small wind turbine (Fig. 13). These generators have a number of advantages, which are:

(a) Simple and more effective configuration in the rotor with permanent magnet.

(b) Overall weight and volume significantly reduced for a given output power (high power density).

(c) Higher efficiency and self excited.

(d) Heat efficiently dissipated to surroundings.

In the PMSG the air-gap flux density can be increased by increasing the thickness of the magnets. The air-gap flux density in the PMSG machine is approximated by the following equation [27]:

$$B_m = B_r \frac{k_{leak}}{1 + \frac{\mu_r * g * k_{carter}}{h_m}} \quad (6)$$

Where:

h_m : magnet thickness,

B_r : residual flux density for the magnet. For NdFe35, it's 1.23 T.

g : minimum air-gap length,

μ_r : relative recoil permeability for the magnet. For NdFe35, it's 1.09981.

k_{leak} : leakage factor. Typically in the range of 0.9 to 1.0 for surface-mounted PM machine.

k_{carter} : Carter coefficient. Typically in the range of 1.0 to 1.1 for surface-mounted PM machine.

Although the PM machine can achieve a larger air-gap flux density and the stator bore diameter is smaller. Moreover, the advantage of the PM machine design is that it has a much higher efficiency (97 %) than the induction machine (85 %).

Due to their excellent performance especially, efficiency and reliability, the general trend in wind industry is to go for higher powers, which is especially relevant with harsh environment. it has become more and more popular during this year's. where several companies have been tried this concept:

Jeumont (0.75 MW), Vensys (1.5 MW), Leitner (1.5 MW), Harakosan (2 MW), Mitsubishi (2 MW), Siemens (3.6 MW), and TheSwitch (4.25 MW) [27]. In [31] work, there are summary of commercial wind turbine with synchronous machine (Large than 1MW).

For illustration, Fig. 13 shows industrial PMSG 1650-6300 kW, 11-17 rpm. TheSwitch company wind power generators [29].

Fig. 13. Industrial permanent magnet synchronous generator.

Many authors examine the benefits and the physical and economic limitations of PMSGs and consider their appropriateness as a key piece in the overall wind turbine system design [28-33]. The reported results are promising.

From analysis of the commercially available wind turbine generators, the elimination of the gearboxes and the power electronic converters will significantly increase the system reliability. The overall system efficiency will increase because the losses in the gearbox and power electronic converters are eliminated, it is concluded that direct drive, grid connected generators indicate a future trend in the wind generation. Finally, the reported results are promising, however, the requirement of PM materials restricts the applications of PMSG, either for high cost or potential to demagnetization in harsh environment.

3.4. Switched Reluctance Generator (SRG)

An innovative Switched Reluctance Generators are gaining much interest and are recognized to have potential for wind power applications, the structure of a 6/4 SRG, as shown in Fig.1 (d). These generators have the definite advantages of simple and rugged construction, fault-tolerant operation, simple control, and outstanding torque-speed characteristics (Fig. 14). SRG can inherently operate with extremely long constant power range. There are, however, several disadvantages, which for many applications outweigh the advantages. Among these disadvantages, acoustic noise generation, torque ripple, special converter topology, excessive bus current ripple, electromagnetic interference (EMI) noise generation. All of the above advantages as well as the disadvantages are quite critical for wind power applications. Nevertheless, SRG is a solution that is actually envisaged in the future for wind energy applications (Fig. 15) [6].

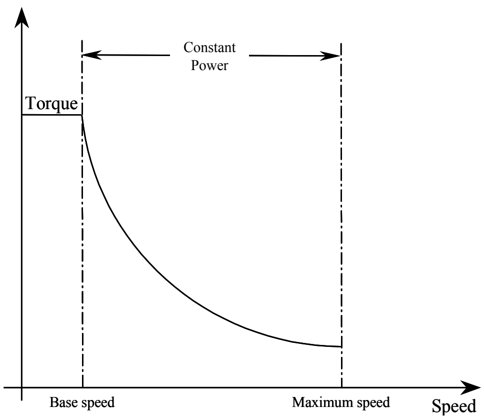


Fig. 14. Typical torque-speed characteristic of a switched reluctance motor.

Fig. 15. Stator and rotor of the 20kW switched reluctance machine.

Jebaseeli has highlighted the performances of the machine for this particular application in [7]. This paper has presented simulate process of the SRG with three different winding constructions in advanced variable-speed wind turbines, showing the SRG systems offer improved efficiency and reduced cost over the conventional generator. H. Chen has proven that the wind turbine generating system can be easily controlled and implemented with SRG, which has the control simplicity. In addition, the SRG can offer high efficiency over a very wide speed range with a rotor structure that is compatible with high speeds and tolerant of extreme environments [12], [34]. In an industrial point of view, the application of the SRM in some of the industrialist and companies is very limited, where many of the applications are categorized as low-, medium-, and high-power and high speed drives for rotary motor drives. Some emerging applications and underwater applications are given in [35]. Finally, if reluctance machines are combined with direct drive features, the machine would be extremely large and heavy, making them less favorable in wind power applications.

3.5. Industrial applications

Table 1 briefly reviews the top manufacturers recently adopted in the wind power industry. Other examples corresponding more to the generators for wind power concepts are given in [2], [7], [29], [36-46].

Table 1. The top wind turbine manufacturers by market.

	Name of company	MW	Generation system
Vestas	Vestas Denmark	3	PMSG
SINOVEL	Sinovel China	3	DFIG
GOLDWIND	Gold wind China	2.5	PMSG
Gamesa	Gamesa Spain	2	DFIG
ENERCON ENERGY FOR THE WORLD	Enercon Germany	2	PMSG
GE Energy	GE energy United States	3.6	DFIG
SUZLON	Suzlon India	2.1	DFIG
SIEMENS	Siemens Germany	3.3	PMSG
MINGYANG WIND POWER 明阳风电	Ming yang wind power/China	2.5-3	PMSG
THE SWITCH	Theswitch China	3.8	PMSG

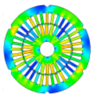
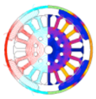
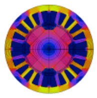
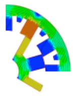
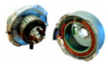
3.6. Preliminary conclusion and perspectives

The permanent magnet synchronous generator seems to be the most adapted candidate for the wind power systems. In fact, this solution is a consensual one as illustrated by the evaluation summarized in Table 2 and based on the main characteristics of the wind power systems, each of them is graded from 1 to 5 points, where 5 points means the best. In our comparative study we have implicitly given the same weight to all the characteristic factors so as to cover a wide range of wind turbine applications, Otherwise, some of these factors should be weighted according to the application.

For example, in [47], the generator choice is determined by four criteria: reliability and ease of maintenance; total weight of the nacelle; energy yield and grid integration issues and cost. Another example is nacelle in the harsh and variable environment where reliability and technological maturity are much more important than efficiency. In some cases, this could lead to another classification.

However, among the mentioned wind generator features, the torque density and energy efficiency are the two basic characteristics that are influenced by wind turbine dynamics and system architecture. Therefore, the selection of the electric generation system for wind energy demands special attention on these two characteristics.

Table 2. Wind power systems evaluation.

Generation Systems / ***Characteristics***	 **DFIG**	 **IG**	 **PMSG**	 **SRG**
Power Density	4.5	3.5	5	3.5
Efficiency	4	3.5	5	3.5
Controllability	5	4	5	4
Reliability	4	3	4	5
Technological maturity	5	5	4	4
weight	3.5	3.5	5	2
Cost	4	4	3	5
∑ Total	 30	 26.5	 31	 26

From this analysis, a conclusion that should be drawn is that permanent magnet synchronous generators are an alternative (Table 2). This is why competition remains hard between the DF induction and PM generators. In this context, some manufacturers try to combine the advantages of these two machines.

Recently, an innovative switched reluctance generator is gaining much interest and is recognized to have potential for wind power applications [48-50]. Other researchers optimize their control and characteristics in this domain. The developed generator can produce excellent performance without using permanent magnet and copper materials, which means reduced manufacturing costs and operation at higher temperatures and higher speed.

4. Conclusion

In this paper, potential candidates of wind power applications have been presented and evaluated according to major requirements of a wind energy system. The comparative study has revealed that the permanent magnet synchronous generator is the solution that makes the consensus even if competition remains hard with doubly-fed induction generator. Moreover, in this paper there was an innovative generator that is gaining much interest and is recognized to have potential for wind power applications in the near future, whilst cage induction generators are dropping.

References

[1] T. Dang & M. H. Rashid, Introduction, history, and theory of wind power, *IEEE NAPS,* 001-006, 2009.

[2] K.W.E. Cheng, J.K. Lin, Y.J. Bao & X.D. Xue, Review of the wind energy generating system, *APSCOM,* 001-007, 2009.

[3] M. Jamil & R. Gupta, A Review of power converter topology used with PMSG based wind power generation, *In Proceedings of the Power India Conference,* 001-006, 2012.

[4] A.D. Hansen & L. H. Hansen, Wind turbine concept market penetration over 10 years (1995 - 2004), *Wind Energy, 10*(1), 081-097, 2007.

[5] Y. Amirat, M.E.H. Benbouzid, B. Bensaker & R. Wamkeue, Generators for wind energy conversion systems: State of the art and coming attractions, *Journal of Electrical Systems, 3*(1), 026-038, 2007.

[6] M.A. Mueller, Design and performance of a 20kW, 100rpm, switched reluctance generator for a direct drive wind energy converter, *IEEE IEMDC,* 056-063, 2005.

[7] E.A.E. Jebaseeli & D. Susitra, Performance Analysis of various configurations of switched reluctance machine for wind energy applications, *IEEE RSTSCC,* 419-423, 2010.

[8] B. Beltran, Contribution à la Commande Robuste des Eoliennes à Base de Génératrices Asynchrones Double Alimentation : Du Mode Glissant Classique au Mode Glissant d'Ordre Supérieur, *PhD Thesis (in French), University of Brest,* 2009.

[9] B. Wu, Y. Lang, N. Zargari & S. Kouro, Power Conversion and Control of Wind Energy Systems, *Wiley-IEEE Press,* 2011.

[10] E. Hau, Wind-Turbines Fundamentals, Technologies, Application, Economics, *Springer,* 2000.

[11] R. Cardenas, W. F. Ray & G.M. Asher, Switched reluctance generators for wind energy applications, *IEEE PESC, 1*, 559-564, 1995.

[12] D.A. Torrey, Switched reluctance generators and their control, *IEEE Transactions on Industrial Electronics, 49*(1), 00 3-014, 2002.

[13] J. A. Baroudi, V. Dinavahi & A. M. Knight, A review of power converter topologies for wind generators, *Renewable Energy, 32,* 2369-2385, 2007.

[14] S. Mathew, Wind Energy, Fundamentals, Resource Analysis and Economics, *Springer-Verlag Berlin Heidelberg* 2006.

[15] S. Soter & R. Wegener, Development of induction machines in wind power technology, *IEEE IEMDC, 2*, 1490-1495, 2007.

[16] V. Kinnares & B. Sawetsakulanond, Characteristic requirements of a small scale squirrel cage induction generator for effective electricity generation from wind energy, *Energy Procedia, 34*, 026-049, 2013.

[17] L.H. Hansen, E. Blaabjerg, H.C. Christensen & U. Lindhard, Generators and power electronics technology for wind turbines, *IEEE IECON,* 3, 2000-2005, 2001.

[18] http://www.abb.com/product/ap/seitp322/ef3aa662ddcbbca5c2256de3003dc875.aspx

[19] http://ele.aut.ac.ir/~wind/en/tour/wtrb/electric.htm

[20] R. Takahashi, H. Ichita, J. Tamura, M. Kimura, M. Ichinose, M. Futami & K. Ide, Efficiency calculation of wind turbine generation system with doubly-fed induction generator, *ICEM,* 001-004, 2010.

[21] http://www.repower.fr/fileadmin/download/produkte/PP_3.2M114_FR.pdf.

[22] A. Petersson, Analysis, modeling and control of doubly-fed induction generators for wind turbines, *PhD Thesis, Chalmers University of Technology,* 2005.

[23] Y. Yongbo, J. Bo, Y Huayun, A. Bing & Z. Xiaoming, Aggregating DFIGS in power system online analysis, *IEEE PEAM, 2, 0*63-067, 2011.

[24] H. Polinder, F. F. A. van der Pijl, G. J. d. Vilder & P. J. Tavner, Comparison of direct-drive and geared generator concepts for wind turbines, *IEEE Transactions on Energy Conversion, 21*(3), 725-733, 2006.

[25] J. Bhukya, Modeling and analysis of double fed induction generator for Variable Speed Wind Turbine, *IEEE ICEETS,* 1324-1329, 2013.

[26] S. Muller, M. Deicke & R. W. de Doncker, Doubly fed induction generator systems for wind turbines, *IEEE Industry Applications Magazine, 8*(3), 026-033, 2002.

[27] Y. Duan, R. G. Harley & T. G. Habetler, Multi-objective design optimization of surface mount permanent magnet machine with particle swarm intelligence, *IEEE SIS,* 001-005, 2008.

[28] Z. Zhang, A. Matveev, S. Øvrebø, R. Nilssen & A. Nysveen, Review of modeling methods in electromagnetic and thermal design of permanent magnet generators for wind turbines, *IEEE ICCEP,* 377-382, 2011.

[29] http://www.theswitch.com/

[30] R. Scott Semken, M. Polikarpova, P. Roytta, J. Alexandrova, J. Pyrhonen, J. Nerg, A. Mikkola, & J. Backman, Direct-drive permanent magnet generators for high-power wind turbines: benefits and limiting factors, *IET Renewable Power Generation, 6*(1), 001-008, 2012.

[31] J.A. Baroudi, V. Dinavahi, & A. M. Knight, A review of power converter topologies for wind generators, *IEEE IEMDC,* 458-465, 2005.

[32] X. Yang, D. Patterson & J. Hudgins, Permanent magnet generator design and control for large wind turbines, *IEEE PEMWA,* 001-005, 2012.

[33] T.F. Chan & L.L. Lai, Permanent-magnet machines for distributed power generation: A review, *IEEE PES GM,* 001-006, 2007.

[34] H. Chen, C. Zhang & X. Zhao, Research on the switched reluctance wind generator system, *IEEE ICSMC, 3,* 1936-194, 2001.

[35] R. Krishnan, Switched Reluctance Motor Drives: Modeling, Simulation, Analysis, Design, and Applications, *Magna Physics Publishing,* 2001.

[36] Y. Duan & R. G. Harley, Present and future trends in wind turbine generator designs, *IEEE PEMWA,* 001-006, 2009.

[37] H. Polinder, J. A. Ferreira, B. B. Jensen, A. B. Abrahamsen, K. Atallah & R. A. McMahon, Trends in wind turbine generator systems, *IEEE Journal of Emerging and Selected Topics in Power Electronics, 1*(3), 174-185, 2013.

[38] Manufacturer VESTES: http://www.vestas.com/

[39] Manufacturer SINOVEL: http://www.sinovel.com/

[40] Manufacturer SUZLON: http://www.suzlon.com/index.aspx

[41] Manufacturer GAMESA: http://www.gamesacorp.com/es/

[42] Manufacturer ENORCON: http://www.enercon.de/de-de/

[43] Manufacturer GEENERGY: http://www.ge-energy.com/wind

[44] Manufacturer GOLDWIND: http://www.goldwindglobal.com/web/index.do

[45] Manufacturer SIEMENS: http://www.siemens.com/innovation/apps/pof_microsite/_pof-spring-2013/_html_en/wind-power.html

[46] Manufacturer MING YANG WIND: http://www.mywind.com.cn/English/index.aspx

[47] H. Tiegna, Y. Amara, G. Barakat & B. Dakyo, Overview of high power wind turbine generators, *IEEE ICRERA,* 001-006, 2012.

[48] A. Lebsir, A. Bentounsi, M.E.H. Benbouzid, R. Rebbah & S. Belakehal, Comparative study of PMSM and SRM capabilities, *IEEE POWERENG,* 760-763, 2013.

[49] H. Chan, Implementation of a three-phase switched reluctance generator system for wind power applications, *IEEE SELT,* 001-006, 2008.

[50] V. B. Koreboina & L. Venkatesha, Modelling and simulation of switched reluctance generator control for variable speed wind energy conversion systems, *IEEE PEDES,* 001-006, 2012.